Write your **student number** in the boxes above. **Letter**

Chemistry ¾ (Flipped)

Question and Answer Book - SOLUTIONS

VCE Examination (Term 1 Mock) – April 2025

- Reading time is **15 minutes**
- Writing time is **2 hours**

Materials Supplied

- Question and Answer Book of 44 pages.
- Multiple-Choice Answer Sheet.

Instructions

- Follow the instructions on your Multiple-Choice Answer Sheet.
- At the end of the examination, place your Multiple-Choice Answer Sheet inside the front cover of this book.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Contents

Student's Full Name: _____

Student's Email: _____

Tutor's Name: _____

Marks (Tutor Only): _____

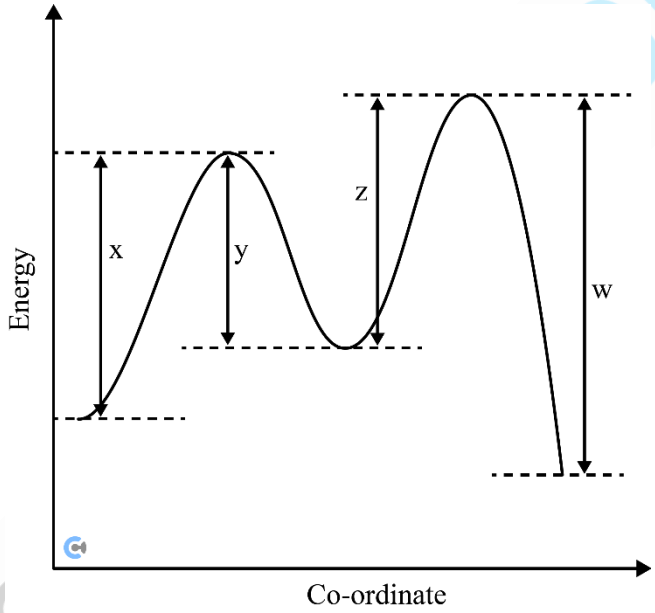
Section A

Instructions

- Answer **all** questions in pencil on the Multiple-Choice Answer Sheet.
- Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer scores 0.
- Marks will **not** be deducted for incorrect answers.
- No marks will be given if more than one answer is completed for any question.
- Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 | D1 | Learning Objective [1.1.1] Identify delta H & Ea in endothermic/exothermic energy profile diagrams.

The energy profile below represents the two steps in a reaction pathway from A to E.



The overall energy change in the two-step process is:

A. Endothermic

B. $w - x$

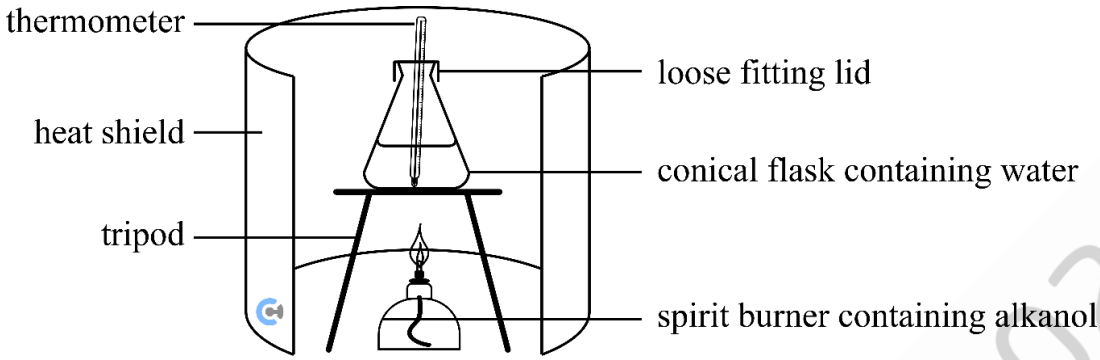
C. $x + z - w - y$

D. $z - y - w$

Question 2 D1

Learning Objective [1.1.2] Identify differences between complete & incomplete combustion & write their thermochemical combustion equations.

The following equipment was set up to measure the heat of combustion of an alkanol.



Black deposits were observed on the bottom of the conical flask and the heat of combustion measured was lower than the theoretical value. Which of the following equations could account for these observations?

A. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

B. $C_3H_8O(g) + 4O_2(g) \rightarrow CO_2(g) + CO(g) + 4H_2O(g)$

C. $2C_4H_{10}O(g) + 3O_2(g) \rightarrow 8C(s) + 2H_2(g) + 8H_2O(g)$

D. $2C_2H_6O(g) + 4O_2(g) \rightarrow 2CO_2(g) + 2C(s) + 6H_2O(g)$

Question 3 D1

Learning Objective [1.6.1] Apply oxidation numbers to find oxidant & reductant.

In which one of the following compounds is sulphur in its lowest oxidation state?

A. SO_3

B. HSO_4^-

C. SO_2

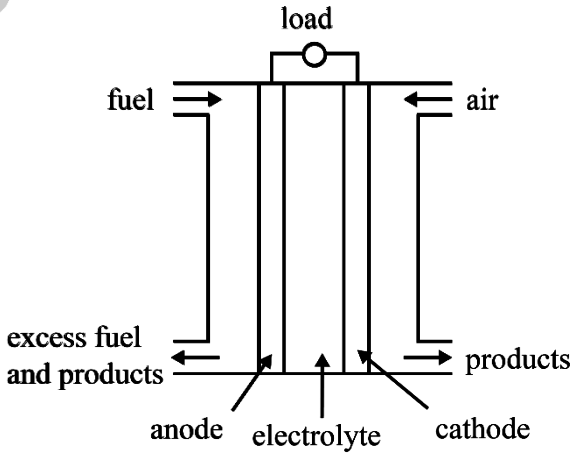
D. Al_2S_3

Question 4 D1

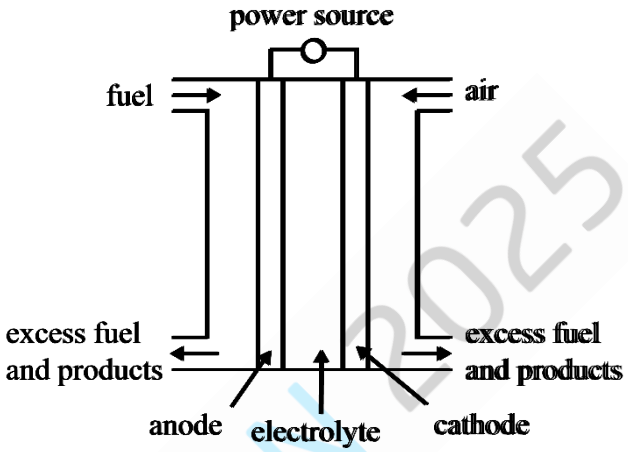
Learning Objective [1.9.2] Identify key features of fuel cell including continuous supply, electrolyte movement and properties of electrodes (PICCY).

Which of the following diagrams shows the common design features of a fuel cell?

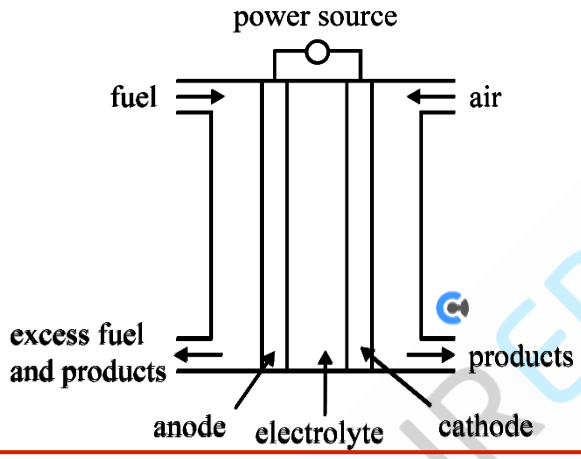
A.



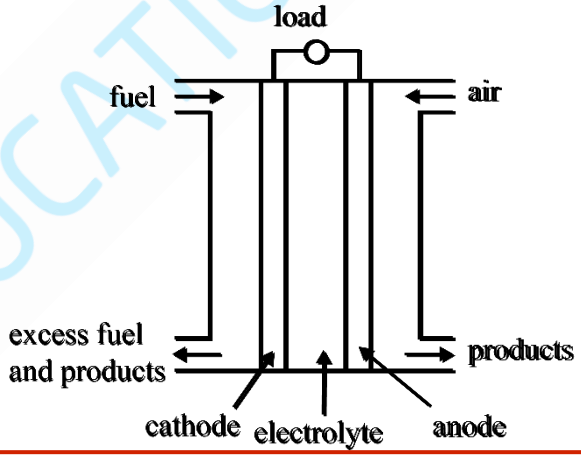
B.



C.



D.



The following information applies to Questions 5 and 6

The complete combustion of $0.500\ mol$ of a hydrocarbon produces $3.00\ mol$ of carbon dioxide during complete combustion. The carbon dioxide is stored at SLC.

D1

Question 5 Learning Objective [1.3.3] Apply m - m, m - v, v - v stoichiometry to calculation questions with equations.

The fuel could be:

A. Butane

B. Propane

C. Hexane

D. Methane

D1

Question 6 Learning Objective [1.3.3] Apply m - m, m - v, v - v stoichiometry to calculation questions with equations.

If the complete $0.500\ mol$ of this fuel were to be combusted, what would be the closest volume of water vapour which would be produced?

A. $0.0\ L$

B. $15\ L$

C. $74\ L$

D. $87\ L$

Question 7 D1 Learning Objective [1.3.4] Identify limiting reagents.

Carbon monoxide can be oxidised to carbon dioxide.

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

$30\ mL$ of CO and $20\ mL$ of O_2 are mixed at SLC.

When the reaction is complete, there will be:

A. $40\ mL$ of CO_2 produced

B. $20\ mL$ of CO_2 produced.

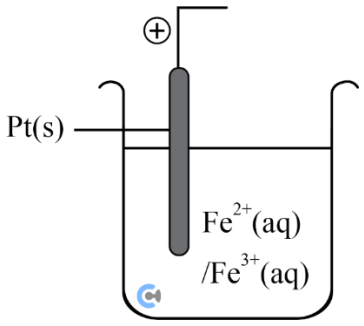
C. $10\ mL$ of CO unreacted.

D. $5\ mL$ of O_2 unreacted.

D1

Question 8 Learning Objective [1.8.2] Write reactions in galvanic cells & calculate the maximum EMF produced.

Consider a galvanic cell that consists of $Fe^{3+}(aq)$ /$Fe^{2+}(aq)$ cell as shown below. What should the other cell be to maximise the cell's theoretical EMF?



A. $Ag^{+}(aq) + e^{-} \rightleftharpoons Ag(s)$

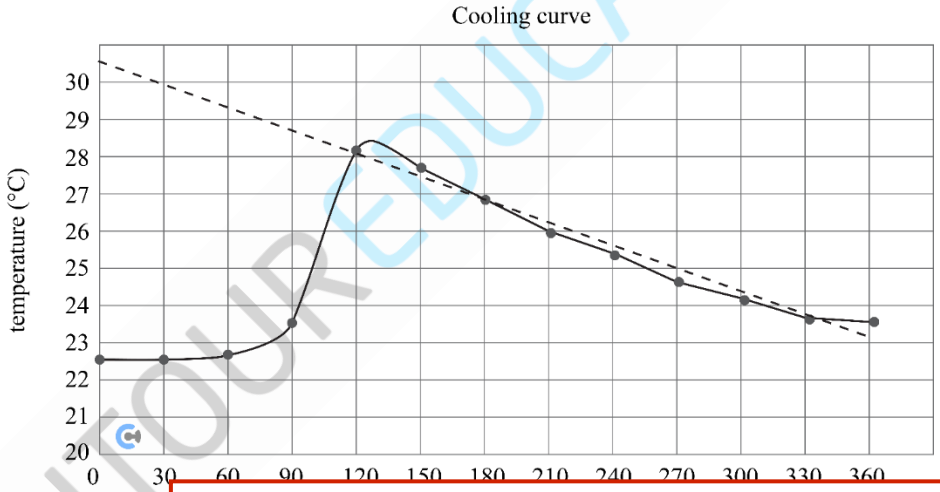
B. $Sn^{4+}(aq) + 2e^{-} \rightleftharpoons Sn^{2+}(aq)$

C. $F_2(g) + 2e^{-} \rightleftharpoons 2F^{-}(aq)$

D. $Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s)$

Question 9 D1 Learning Objective [1.4.3] Apply temperature - time graphs to calorimetry.

Consider the following temperature time graph of the electrical calibration of a calorimeter.



In a calorimeter, products stay inside the calorimeter to avoid heat loss.

A. Better insulation of the calorimeter would have resulted in a flatter dotted line.

B. At time 90 seconds, carbon dioxide is being released from the calorimeter.

C. After a long time, the graph will plateau at a constant value.

D. Better insulation would result in a higher maximum temperature.

D1

Question 10 Learning Objective [1.4.1] Calculate calibration factor via electrical & chemical calibration (CF=E/delta T).

A calorimeter is calibrated by passing 5.0 $amps$ at 10 volts through a calorimeter for 60 seconds. The calorimeter increased in temperature from 24 to 45 degrees Celsius.

What is the calibration factor?

A. $142\ J\ °C^{-1}$

B. $142\ kJ\ °C^{-1}$

C. $14.2\ J\ °C^{-1}$

D. $14.2\ kJ\ °C^{-1}$

Question 11 D1 Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

Which of the following statements is incorrect about biogas?

A. They contain only methane.

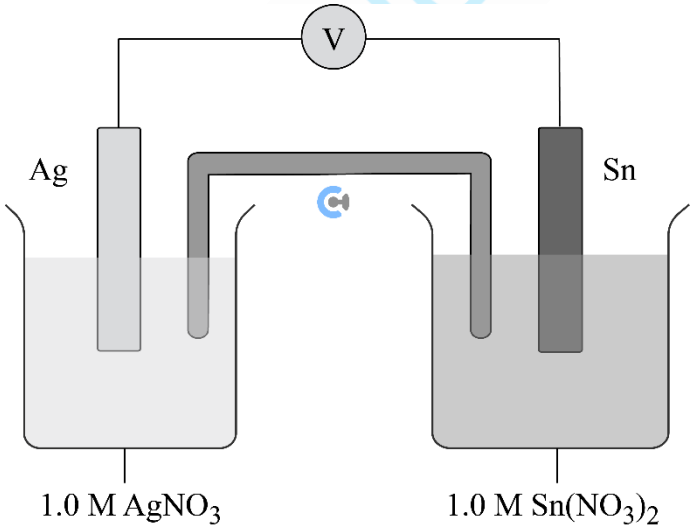
B. They are produced via anaerobic respiration by bacteria.

C. They have a lower energy density than pure methane.

D. They can be produced by most organic matter.

Question 12 D1 Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

The diagram below shows a galvanic cell which is set up in a laboratory under standard conditions.



Which one of the following statements about the cell is correct when electrical energy is being produced?

A. The mass loss of one electrode equals exactly the mass gain of the other electrode.

B. Electrons travel from the positive Ag electrode to the Sn electrode.

C. Positive ions travel towards the half-cell which contains the cathode.

D. As the electrolytes are aqueous, gas bubbles will appear at each electrode surface.

The following information applies to Questions 13 and 14

Various reagents were mixed in separate flasks as shown in the table below.

Flask 1	Flask 2	Flask 3	Flask 4
$Cu(NO_3)_2(aq) + Sn$	$Ag^+(aq) + Sn$	$Fe^{3+}(aq) + NaCl(aq)$	I_2 solution + Cu

Question 13 D1 Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

A reaction is likely to occur in:

A. Flasks 1 and 2 but not in flask 3.

B. Flasks 1 and 3 but not in flask 2.

C. Flask 2 but not in flasks 1 and 3.

D. Flask 3 but not in flasks 1 and 2.

Question 14 D1 Learning Objective [1.7.2] Identify differences between direct & indirect redox reactions, & features of ECS.

Using the electrochemical series, a reaction is predicted to occur in flask 4. However, no reaction had occurred by the time any reactions took place in the other flasks. Which one of the following is the most likely reason to explain this?

A. The iodine was in a different state than that shown in the electrochemical series.

B. The enthalpy change for the reaction has a positive value.

C. An alloy of copper and zinc was used mistakenly in place of pure copper metal.

D. The products are formed much more slowly than products in the other reactions.

Question 15 D1 Learning Objective [1.6.1] Apply oxidation numbers to find oxidant & reductant.

The E^0 values for reduction reactions involving chromium are shown below.

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O \quad +1.36\ V$$

$$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq) \quad -0.41\ V$$

$$Cr^{2+}(aq) + 2e^- \rightleftharpoons Cr\ (s) \quad -0.91\ V$$

The reaction begins with a solution of potassium dichromate. Which of the following could be used to reduce the potassium dichromate from an oxidation state of +6 to +2?

A. Cu

B. Al

C. Zn

D. F^- ions

D1

Question 16 Learning Objective [1.4.1] Calculate calibration factor via electrical & chemical calibration (CF=E/delta T).

Consider the following situations:

I The volume of water surrounding the reaction chamber in the calorimeter was only 90% of the volume specified for the operation of the calorimeter.

II The outer layer of insulation on the calorimeter was removed.

During the calibration of the calorimeter using benzoic acid combustion, which of the above situations would result in a calculated calibration factor which is greater than the actual value?

A. I only.

B. II only.

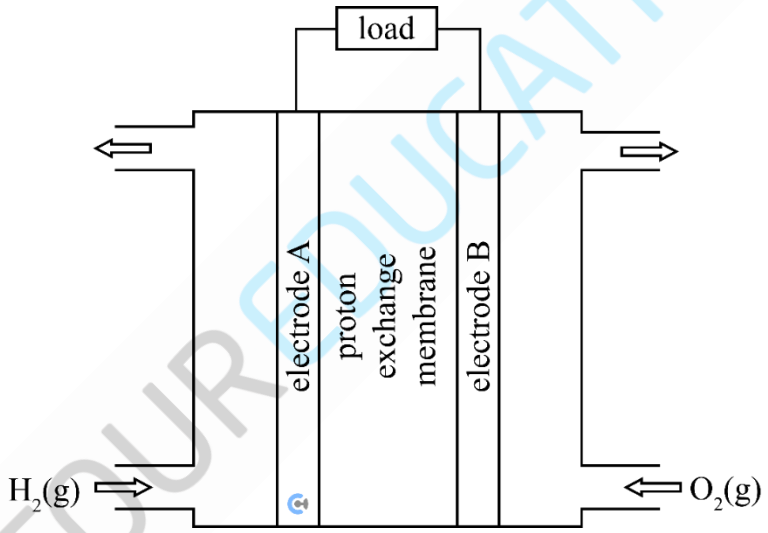
C. Both I and II.

D. Neither I nor II.

Question 17 D1

Learning Objective [1.9.2] Identify key features of fuel cell including continuous supply, electrolyte movement and properties of electrodes (PICCY).

The diagram below shows a typical proton exchange membrane fuel cell.



Which of the following would be correct when this fuel cell is releasing energy?

	Electrode *A*	Electrode *B*	Ion movement in the membrane
A.	Anode	Cathode	OH^- moving from the electrode B to electrode A.
B.	Cathode	Anode	H^+ moving from the electrode B to electrode A.
C.	Cathode	Anode	OH^- moving from the electrode A to electrode B.
D.	Anode	Cathode	H^+ moving from the electrode A to electrode B.

Question 18 D1 Learning Objective [1.10.3] Calculate the Charge of a Metal.

In an experiment, the charge of vanadium ions is to be investigated. After $5000\ C$ is passed through the cell, $0.88\ g$ of vanadium is found to react.

The charge on the vanadium ions is:

A. $+1$

B. $+2$

C. $+3$

D. $+4$

Question 19 D1 Learning Objective [1.2.3] Apply $q = mcAT$ to find energy absorbed.

A sample of fuel is completely combusted, whereby $372\ kJ$ of energy is released and is used to heat $1.50\ L$ of water at SLC. What is the final temperature reached by the water?

A. $0.059℃$

B. $0.248℃$

C. $59℃$

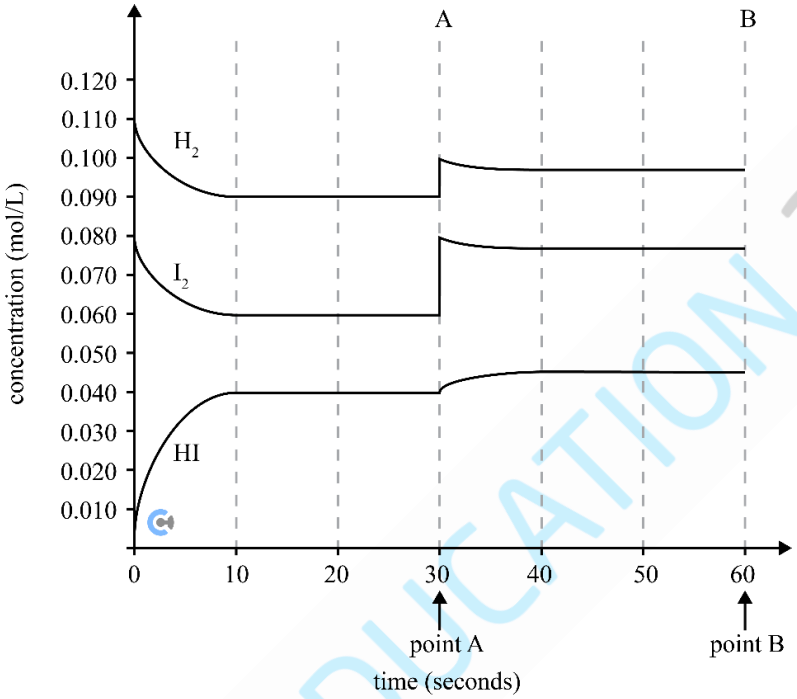
D. $84℃$

The following information applies to Questions 20 and 21

The reaction between $H_2(g)$ and $I_2(g)$ in a $1.0\ L$ container was observed to be:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \Delta H = -ve$$

During the reaction, the temperature was kept at $200°C$. The concentration versus time graph for this reaction was determined and is shown below.



Question 20 D1 Learning Objective [2.7.1] Write equilibrium constant expression & find its value (including units).

The value of K_c when the system first reaches equilibrium is closest to:

A. 0.25

B. 0.30

C. 3.33

D. 7.41

Question 21 D1 Learning Objective [2.9.3] Find the change made to system from equilibrium graph.

What change occurred at Point A?

A. The volume of the vessel was decreased, changing the value of K.

B. The volume of the vessel was decreased, without a change in the value of K.

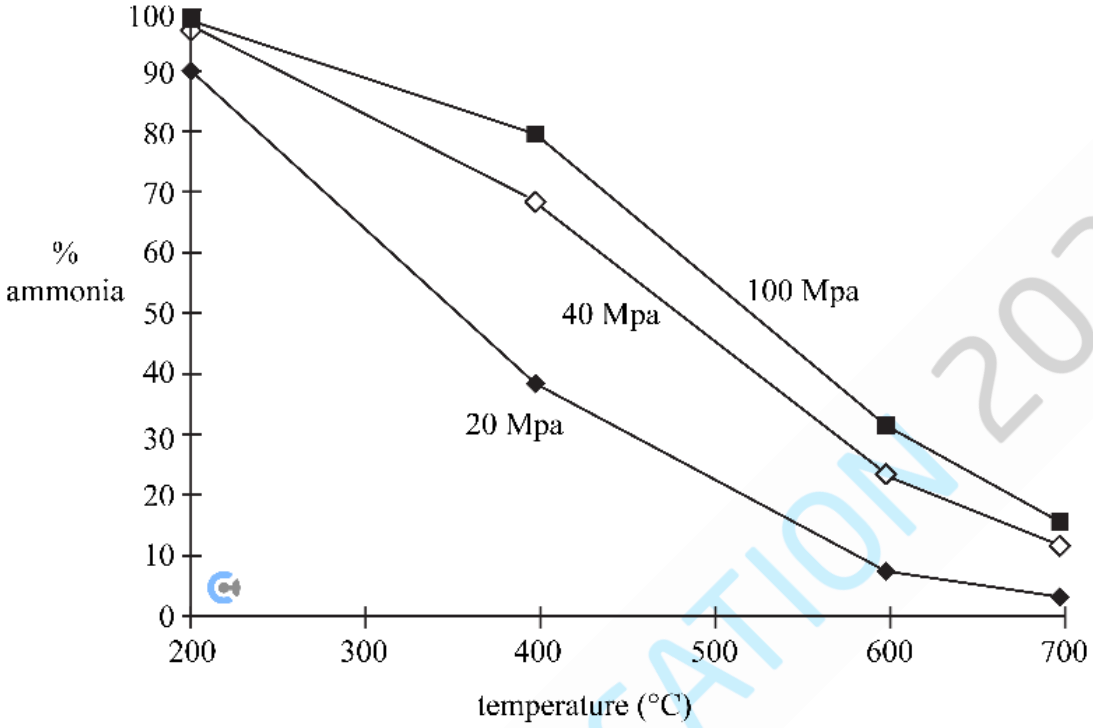
C. $H_2(g)$ and $I_2(g)$ were added, changing the value of K.

D. $H_2(g)$ and $I_2(g)$ were added, without a change in the value of K.

Learning Objective [2.9.5] Find optimum operating conditions in all circumstances such as the rate-yield conflict.

Question 22 D1

The percentage of ammonia formed from its elements is plotted against temperature for three different pressures below.



Which of the following conditions would not increase the yield of ammonia?

A. High pressures.

B. Low temperatures.

C. Addition of a catalyst.

D. Decreasing the volume of the vessel in which the reaction is occurring.

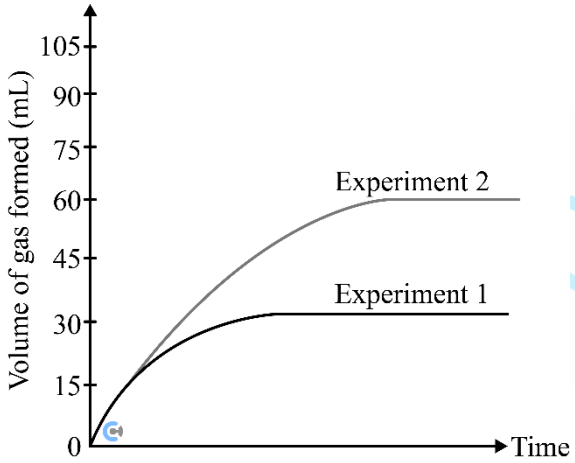
Question 23 D1 Learning Objective [2.6.3] Graph differences in rate & yield.

Hydrochloric acid reacts with zinc metal according to the following reaction.

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Two experiments are carried out. Experiment 1 involves $150\ mL$ of $0.10\ M$ hydrochloric acid with $2.50\ g$ of solid strips of zinc metal at $25℃$.

Some factors are changed in experiment 2. The volume of hydrogen gas evolved for both reactions is captured and measured, as shown in the graph below.



Which of the following factors could have been changed in experiment 2 to result in the results shown in the graph above?

A. Concentration of hydrochloric acid is doubled from $0.10\ M$ to $0.20\ M$ in the same volume.

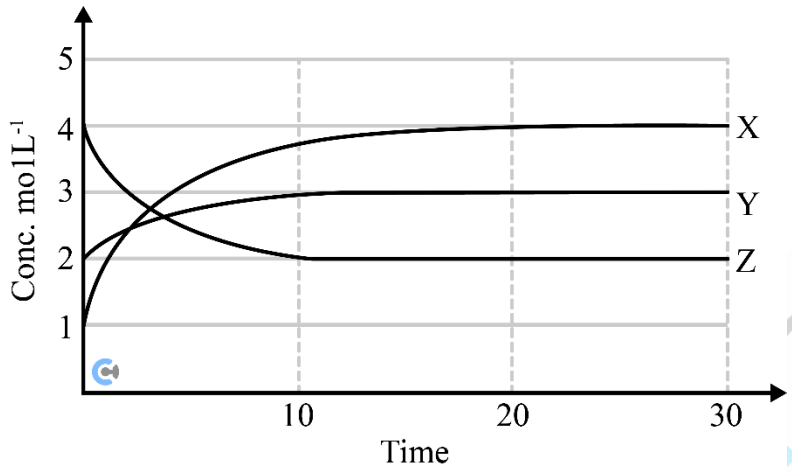
B. Temperature is increased to $35℃$.

C. $300\ mL$ of $0.10\ M$ HCl is used instead.

D. $5.0\ g$ strips of zinc metal are finely divided into smaller pieces instead.

Question 24 D1 Learning Objective [2.7.5] Apply RICE tables to find Kc.

The graph below shows the concentrations, as a function of time, for a mixture of gases, X, Y and Z reacting and achieving equilibrium in a 1 L. vessel.



The equation describing the equilibrium system is:

A. $X + Y \rightleftharpoons Z$

B. $3X + Y \rightleftharpoons 2Z$

C. $Z \rightleftharpoons X + Y$

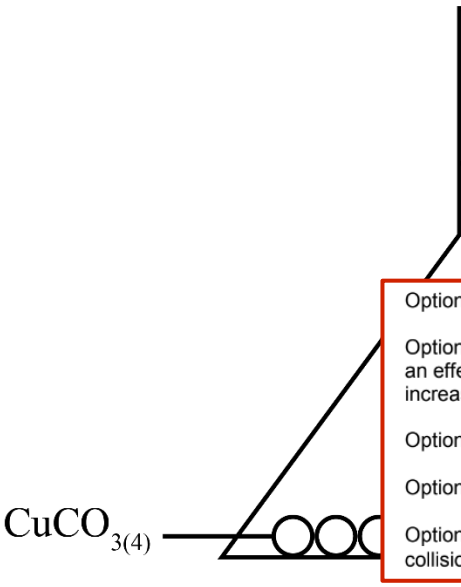
D. $4Z \rightleftharpoons X + 2Y$

B The concentration time graph shows tat in getting to equilibrium
[X] has increased from 1 M to 4 M, ie by 3 M or 3 mol in 1 L
[Y} has increased from 2 M to 3 M, ie by 1 M or 1 mol in 1 L
[Z] has decreased from 4 M to 2 M, ie by 2 M or 2 mol in 1 L
So in effect **2 mol Z** has reacted to produce **3 mol X** and **1 mol Y** ie $2\ Z \rightarrow 3\ X + Y$
this is consistent with the equilibrium $2\ Z \square 3\ X + Y$ being established from the reaction side, or the equilibrium **3 X + Y** □ **2 Z** being achieved from the product side.

Question 25 D1

Learning Objective [2.6.1] Explain how factors increase frequency of collisions.

Which one of the following options will increase the rate of reaction?



Option I is incorrect as surface area doesn't apply to solutions.

Option II is correct. As the surface area of the calcium carbonate increases, the probability of an effective collision between reactant particles increases. Therefore, the reaction rate increases.

Option III is incorrect as pressure does not affect solid or aqueous reactants.

Option IV is incorrect, a decrease in pressure does not affect aqueous or solid reactants.

Option V is correct. As the concentration of *HCl* increases, the probability of an effective collision between reactant particles increases. Therefore, the reaction rate increases.

I Increase the surface area of the HCI solution.

II Increase the surface area of copper carbonate.

III Increase the pressure in the conical flask.

IV Remove carbon dioxide gas.

V Increase the concentration of HCI.

A. I, II

B. I, III

C. II, V

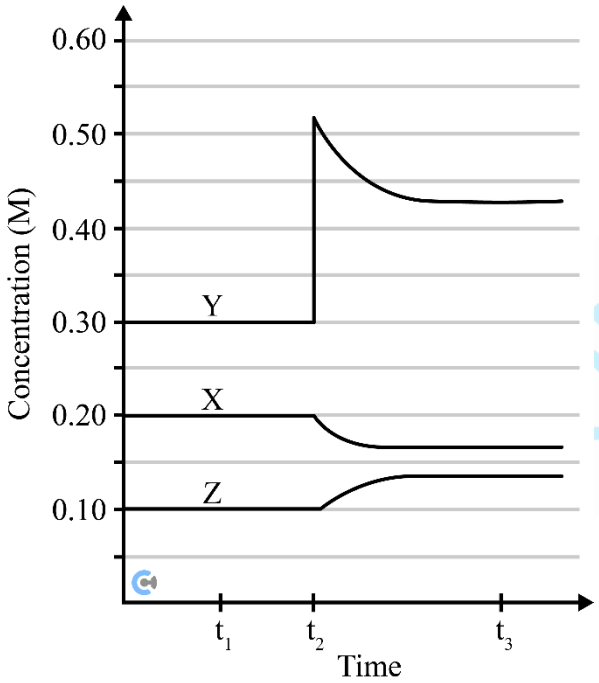
D. II, IV

Question 26 D1 Learning Objective [2.9.3] Find the change made to system from equilibrium graph.

The gases X, Y, and Z were placed in an evacuated vessel and allowed to reach equilibrium according to the equation:

$$X(g) + 2Y(g) \rightleftharpoons Z(g) \quad \Delta H = -300\ kJ\ mol^{-1}$$

At time t_2, a change was made, and the effect on the concentration of the gases was graphed, as shown below. The temperature remained constant throughout the experiment.



What occurred at t_2?

A. More of Y was added.

B. Volume was decreased.

C. Catalyst was added.

D. Temperature was increased.

The following information applies to Questions 27 and 28

The following reaction is considered.

$$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g) \quad K_c = 3.80 \text{ at } 200°C$$

Question 27 D1 Learning Objective [2.7.3] Find equilibrium constant when equation is changed.

The equilibrium constant for the following equation is:

$$HCl(g) \rightleftharpoons \frac{1}{2}H_2(g) + \frac{1}{2}Cl_2(g)$$

A. 0.132

B. 0.513

C. 1.95

D. −1.90

Question 28 D1 Learning Objective [2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.

It is found that chlorine gas has a greenish-yellow colour. How the intensity of the greenish-yellow colour will change if the following changes were made?

	Chlorine is removed	Volume is doubled
A.	Increase intensity	No change to intensity
B.	Increase intensity	Decrease intensity
C.	Decrease intensity	No change to intensity
D.	Decrease intensity	Decrease intensity

Question 29 D1

Learning Objective [2.9.4] Find equilibrium constant changes due to temperature.

The following reaction occurs:

$$X + Y \rightleftharpoons 2Y + Z \quad \Delta H = +350\ kJ\ mol^{-1}$$

A change is made which causes the K_c value to decrease.

The change which was made is:

A. Volume decreased.

B. Catalyst was added.

C. Temperature was increased.

D. Temperature was decreased.

Question 30 D1

Learning Objective [2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.

Consider the following reaction, which has an endothermic forward reaction.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

Chlorine gas is greenish-yellow in colour.

Which of the following changes will cause an increase in the intensity of the greenish-yellow colour?

A. Decreasing temperature.

B. Adding a small amount of nitrogen monoxide.

C. Removing a small amount of chlorine gas.

D. Decreasing volume.

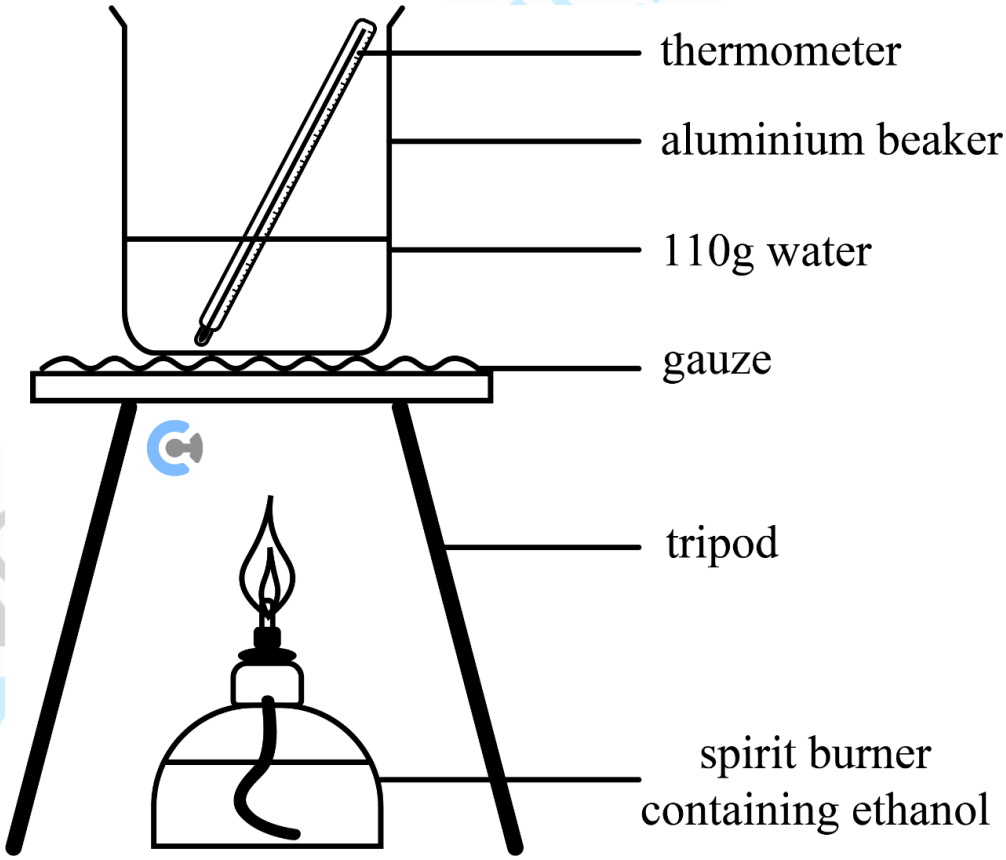
Section B

Instructions

- Answer all questions in the spaces provided.
- Write your responses in English.
- Give simplified answers to all numerical questions, with an appropriate number of significant figures; unsimplified answers will not be given full marks.
- Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.
- Ensure chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H2(g)$, $NaCI(s)$.
- Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 (7 marks)

The following apparatus was used in an experiment to determine the molar enthalpy of the combustion of ethanol.



a. Calculate the experimental molar enthalpy of combustion (ΔH) of ethanol when $0.590\ g$ ethanol was used to raise the water temperature from $12.5℃$ to $40.0℃$. 4 marks

D2

Learning Objective [1.2.4] Calculate delta H experimentally.

$n(C_2H_5OH) = \frac{m}{Mr} = \frac{0.590}{46} = 0.012826\,mol$ (1)

$q = mc\Delta T = 110 \times 4.18 \times (40 - 12.5) = 12644.5\,J$ (1)

$\Delta H = \frac{q}{n} = \frac{12.645\,kJ}{0.01283\,mol} = 985.6\,kJ$ (1)

$\Delta H = -986\ kJ/mol$ (1)

b. Using your answer in **part a.**, find the % energy efficiency of the setup. D1 1 mark

Learning Objective [1.3.1] Identify changes to minimise heat loss & calculate percentage efficiency.

$\%\ efficiency = \frac{986}{1370} \times 100\% = 72.0\%$

c. Explain one change that could be made to the experiment that would improve the accuracy of the obtained value. D3 2 marks

Learning Objective [1.3.1] Identify changes to minimise heat loss & calculate percentage efficiency.

(1) any change to reduce heat loss

- adding a lid

(2) explanation how it improves accuracy.

Lid reduces heat loss, thereby causing a theoretical value closer to the true value and increasing accuracy.

(1 Mark) Adding a heat shield

(1 Mark) A heat shield would prevent heat being lost to the surroundings and hence, reduced heat loss. Thereby, the theoretical value will be closer to the true value increasing accuracy

Question 2 (4 marks)

Hydrogen peroxide is a common cleaning agent used in substances such as bleach.

a. Hydrogen peroxide is then mixed with fluorine gas.

i. Use the information from the electrochemical series in the Data Book to write a balanced overall equation for the reaction which occurs. 2 marks

D2

Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

Reduction: $F_2(g) + 2e^- \rightarrow 2F^-(aq)$

Oxidation: $H_2O_2(aq) \rightarrow O_2(g) + 2H^+(aq) + 2e^-$ ①

Full equation: $F_2(g) + H_2O_2 \rightarrow O_2(g) + 2HF(aq)$ ①

ii. State the energy conversion which takes place as the reaction proceeds. 1 mark

D1

Learning Objective [1.7.2] Identify differences between direct & indirect redox reactions, & features of ECS.

Chemical to thermal.

b. Using data from the electrochemical series, a student suggests that a reaction will occur between acidified hydrogen peroxide and $Ni(s)$. To test this prediction, a strip of nickel metal is dipped into a solution containing 1.0 M acidified hydrogen peroxide at 25°C. No reaction was observed after 2 minutes. 1 mark

D2

Provide one possible chemical reason that explains why the predicted reaction was not observed.

Learning Objective [1.7.2] Identify differences between direct & indirect redox reactions, & features of ECS.

The electrochemical series does not predict the rate of reaction, and the rate of reaction may have been too slow.

Question 3 (7 marks)

In an extended electrochemical series, the following half-equations are investigated.

$$O_3(g) + H_2O(l) + 2e^- \rightleftharpoons O_2(g) + 2OH^-(aq) \qquad E^0 = +1.24\,V$$

$$Y^{3+}(aq) + 3e^- \rightleftharpoons Y(s) \qquad E^0 = -2.37\,V$$

$$In^{3+}(aq) + 3e^- \rightleftharpoons In(s) \qquad E^0 = -0.34\,V$$

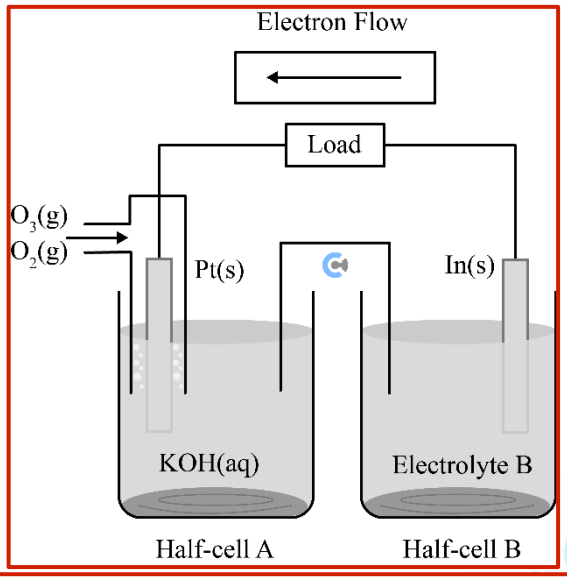
D2

a. A strip of indium metal is dipped into $1.0\,M$ of $Y(NO_3)_3(aq)$ solution. Predict if a reaction is expected to occur. Justify your answer. 1 mark

Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

(1 M) No reaction.
(1 M) $Y^{3+}(aq)$ is a weak oxidant $(E^0 = -2.37\,V)$ and Indium is a weak reductant $(-0.34\,V)$ relative to each other.

b. A galvanic cell is constructed between the ozone/oxygen half-cell and $In^{3+}(aq)/In(s)$, as shown below.



D1 Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

i. In the box provided above, label the direction of electron flow. 1 mark

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

ii. Suggest a suitable substance for electrolyte B. D2 1 mark

$In(NO_3)_3$ or any other electrolyte paired up with a soluble or inert anion.
$In^{3+}(aq)$ alone is not accepted.

iii. Write the balanced equation for the overall reaction which takes place. D1 1 mark

Learning Objective [1.8.2] Write reactions in galvanic cells & calculate the maximum EMF produced.

$3O_3(g) + 3H_2O(l) + 2In(s) \rightarrow 2In^{3+} + 3O_2(g) + 6OH^-(aq)$
or
$3O_3(g) + 3H_2O(l) + 2In(s) \rightarrow 2In(OH)_3(aq) + 3O_2(g)$

iv. A pH meter is inserted into the electrolyte of half-cell A. Explain what would happen to the pH as the reaction proceeds. D1 1 mark

Learning Objective [1.8.3] Identify & explain observations during operation of galvanic cells.

pH increases, as hydroxide ions are formed, making solution more basic.

c. In the salt bridge, potassium nitrate ions are present.

i. State **one** function of the salt bridge. 1 mark

D1

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

(1 M to one of) completes circuit / balances build-up of charge / maintains electric neutrality.

ii. State **one** property of the potassium nitrate ions which helps with the operation of the cell. 1 mark

Learning Objective [1.8.1] Identify electrodes, salt bridge/electron movement during galvanic.

D1

(1 M to one of) soluble / inert / doesn't form precipitates.

Question 4 (3 marks)

Most batteries we use for household appliances are often categorised as alkaline batteries. Contour Industries is now trying to venture into the battery business, and Jayden is the lead researcher on batteries. The battery contains zinc metal ($Zn(s)$) and manganese dioxide ($MnO_2(s)$) which can produce zinc oxide ($ZnO(s)$) and manganite ($MnOOH(s)$).

a. Jayden must now figure out where to place these reactions in the alkaline battery.

i. Write the reaction occurring at the anode. 1 mark

D1

Learning Objective [1.6.2] Apply KOHES to write balanced half-equations in acidic & basic conditions.

$Zn(s) + 2OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$ (negative polarity)

ii. Write the reaction occurring at the cathode. 1 mark

D1

Learning Objective [1.6.2] Apply KOHES to write balanced half-equations in acidic & basic conditions.

$MnO_{2(s)} + H_2O_{(l)} + e^- \rightarrow MnOOH_{(s)} + OH^-_{(aq)}$

b. A pacemaker is a small medical device placed in the chest to correct certain heart problems. While this type of battery is commonly used in appliances, it is not suitable for use in a pacemaker. Explain this phenomenon. 1 mark

D1

Learning Objective [1.10.1] Identify features of primary cells & how they operate.

This is not suitable for a pacemaker due to $ZnO(s)$ a product, being toxic towards humans to ingest. (don't swallow batteries)

OH^- ions are produced. In high concentrations, this can be harmful for the body.

Do not write in this area.

Question 5 (6 marks)

A solution calorimeter was used to experimentally determine the heat of the solution of potassium nitrate when it is dissolved in water. The calorimeter is found to have had a calibration factor of $2.5\ kJ\ °C^{-1}$.

It is found that the experimental heat of the solution of potassium nitrate is $+35.0\ kJ\ mol^{-1}$.

a. Write the balanced thermochemical equation for the dissolution reaction which occurs. 1 mark

D1

Learning Objective [1.1.2] Identify differences between complete & incomplete combustion & write their thermochemical combustion equations.

$$KNO_3(s) \rightarrow KNO_3(aq) \qquad \Delta H = +35.0\ kJ\ mol^{-1}$$

b. A $30.0\ g$ sample of the potassium nitrate is dissolved in water at SLC.

i. Find the amount of energy, in kilojoules, which was absorbed by the reaction. D2 2 marks

Learning Objective [1.2.1] Apply delta H = q x n to energy released.

$n(KNO_3) = \frac{m}{M} = \frac{30}{39.1+48+14}$

$= 0.297\ mol$ (1)

$q = \Delta H \times n$

$= 35\ kJ/mol \times 0.297\ mol$

$= 10.4\ kJ$ (3 s.f) (1)

ii. Using the calibration factor given and your answer from **part b. i.**, find the final temperature reached, after the $30.0\ g$ of potassium nitrate was completely dissolved into the water. 2 marks

D2

Learning Objective [1.4.2] Apply calibration factor to find energy released (E = CF x delta T).

$CF = \frac{E}{\Delta T}$

$\rightarrow \Delta T = \frac{E}{CF}$

$= \frac{10.4}{2.5\ kJ/°C}$

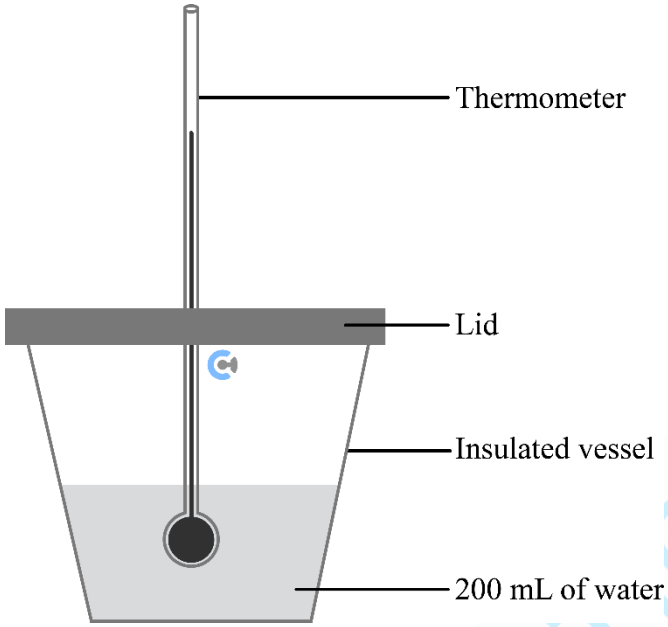
$\Delta T = 4.16$ (1)

$T_f = T_i - T_c$

$= 25°C - 4.16°C$

$= 20.84°C$ (1)

The original calorimeter with a calibration factor of $2.5\ kJ\ °C^{-1}$ which contains $200\ mL$ of water is shown below.



The amount of water present in the calorimeter is increased to $250\ mL$, changing the calibration factor.

c. State whether this new calibration factor will be higher or lower than $2.5\ kJ\ °C^{-1}$. Justify your answer. D2 1 mark

Learning Objective [1.4.1] Calculate calibration factor via electrical & chemical calibration (CF=E/delta T).

Higher – more energy is required to increase temperature of calorimeter by 1°C as there is more water to heat up.

Question 6 (14 marks)

Contour Industries is an up-and-oncoming company looking to expand its outreach to the energy industry. They look for sources of methane.

a. Write the thermochemical equation for the complete combustion of methane. D2 2 marks

Learning Objective [1.1.2] Identify differences between complete & incomplete combustion & write their thermochemical combustion equations.

$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (l)\ \ \Delta H = -890\ kJ\ mol^{-1}$

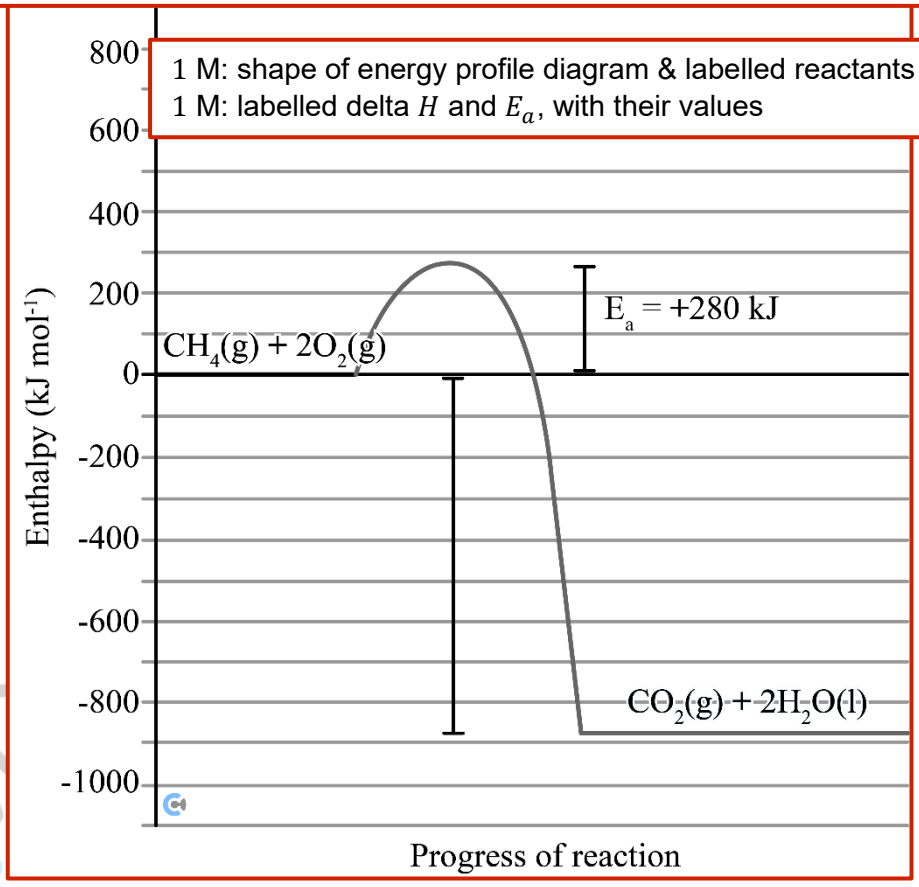
1 M: balanced equation with correct states
1 M: for the delta H value

b. The activation energy for the combustion of methane is $280\ kJ\ mol^{-1}$.

i. Complete the energy profile diagram on the axes provided below. D3 2 marks

Learning Objective [1.1.1] Identify delta H & Ea in endothermic/exothermic energy profile diagrams

1 M: shape of energy profile diagram & labelled reactants and products
1 M: labelled delta H and E_a, with their values



ii. State the activation energy for the reverse reaction. D1 1 mark

Learning Objective [1.1.3] Apply changing equations to thermochemical equations & energy profile diagrams.

890 + 280 = 1170 kJ

c. A surveyor decides whether to drill for natural gas or to obtain methane from biogas.

i. Explain how biogas is produced. D2 1 mark

Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

Anaerobic respiration of organic matter by bacteria/microorganisms

ii. Noah says that 'natural gas is considered to be fossil fuels as it produces greenhouse gases which are harmful to the environment.' D3 2 marks

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

Evaluate Noah's statement, justifying your response.

(1) Noah is correct in saying natural gas is a fossil fuel.

(2) However, it is not due to producing GHG. Rather as it is a non-renewable source of energy which cannot be produced in a relatively short time by natural processes

d. Methane is used as a fuel over alternatives such as methanol. Methanol has a lower heat of combustion in kJ/mol. Explain the differences in the heat of combustion. D2 2 marks

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

(1) Methanol is partially oxidised as it contains an oxygen whereas methane does not and is not oxidised.

(2) Therefore, since combustion is oxidation, methanol is unable to oxidise as much as methane and thus releases less energy.

e. Contour Industries is planning to expand into the domestic stove market with its own natural gas stove, the Burnout Mark IV. Methane is used at high pressure and low temperature, whereby it is compressed and turned into liquified petroleum gas, LPG.

i. Given that this LPG is only made of methane which has a density of $0.580\ g\ mL^{-1}$, find the theoretical volume of LPG, in mL, which is required to obtain $2.00\ MJ$ of energy. 3 marks

Learning Objective [1.2.2] Apply delta H in kJ/mol, kJ/g & kJ/mL to energy calculations.

D2

$$\Delta H = \frac{q}{n},\ n(CH_4) = \frac{q}{\Delta H} = \frac{2000\ kJ}{890\ kJ\ mol^{-1}} = 2.25\ mol\ (1\ M)$$

$$m(CH_4) = n \times M_r = 2.25 \times 16 = 35.96\ g\ (1\ M)$$

$$d = \frac{m}{V},\quad V = \frac{m}{d} = \frac{35.96\ g}{0.580\ g\ mL^{-1}} = 61.99\ L = 62.0\ mL\ (3\ s.f.)\ (1\ A)$$

ii. In practice, the efficiency of the gas stove is 70%, find the amount of energy the experimental volume of LPG required to achieve the same amount of energy as **part e. i.** 1 mark

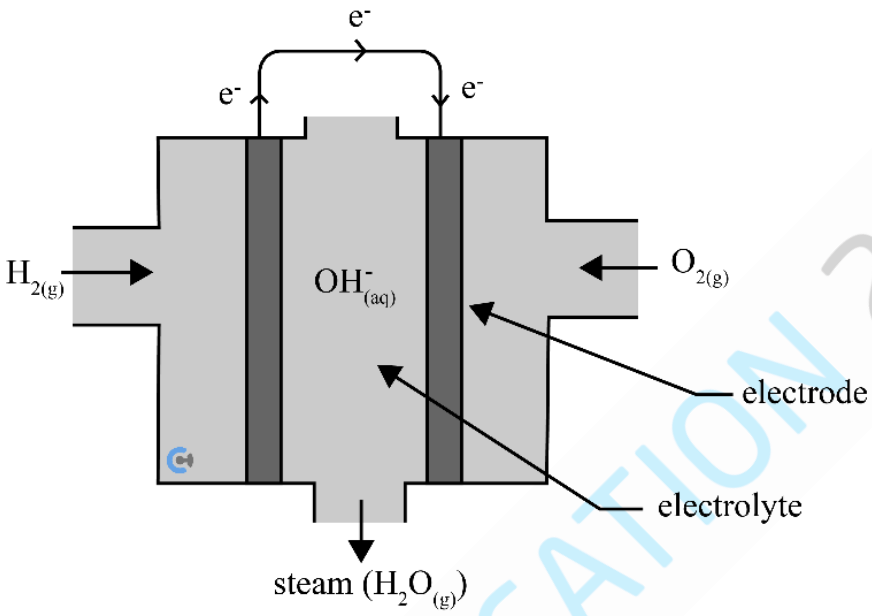
Learning Objective [1.3.1] Identify changes to minimise heat loss & calculate percentage efficiency.

D1

$$actual = \frac{theoretical}{\%eff} = \frac{62\ L}{0.7} = 88.6\ L$$

Question 7 (11 marks)

With society moving to net zero carbon emissions by 2050, cars have started to be developed to be run on hydrogen gas as the main fuel rather than petrol. Some cars have begun development on a hydrogen/oxygen fuel cell, whereby a simplified version is shown below.



The fuel cell consists of two hydrogen gas that is inserted through the left pipe and oxygen gas through another. The two pipes are joined, and the alkaline electrolyte, KOH, passes through the centre of the cell.

D1

a. Write balanced ionic half-equations for the reactions occurring at the anode and cathode. 2 marks

Learning Objective [1.9.1] Write fuel cell half & overall reactions in acidic conditions.

Anode: _____

Cathode: _____

anode: $H_2(g) + 2\,OH^-(aq) \rightarrow 2\,H_2O(l) + 2\,e^-$

cathode: $O_2(g) + 2\,H_2O(l) + 4\,e^- \rightarrow 4\,OH^-$

b. The electrodes consist of a porous nickel alloy mesh. D1 2 marks

State **two** roles that the nickel electrodes play in the operation of the fuel cell.

Learning Objective [1.9.2] Identify key features of fuel cell including continuous supply, electrolyte movement and properties of electrodes (PICCY).

_____

_____

Any two of:
- Act as catalyst.
- Allow the gases to come in contact with electrode.
- Allow oxidation and reduction to occur.

c. Explain one major advantage of the use of hydrogen fuel cells to power cars over combustion engines fuelled by hydrogen by referring to **one** 'Green Chemistry Principles'. Use item **26. ii.** of the Data Book. D2 3 marks

Learning Objective [1.9.3] Explain advantages & disadvantages of fuel cells with reference to green chemistry principles.

(1 M) Design for energy efficiency.
(1 M) Fuel cells have direct conversion from chemical to electrical energy, whereas combustion engines fuelled by hydrogen have multiple energy conversions which leads to more energy loss. This results in greater energy efficiency for fuel cells.
(1 M) With greater efficiency, less fuel is required to produce the same amount of energy, resulting in less $H_2O(g)$ formed, and thus less greenhouse gas emissions, minimising environmental impact.

d. This fuel cell creates a current of $5.60\ A$. Calculate the volume of hydrogen gas consumed at SLC, if the cell runs for $30.0\ min$. D2 4 marks

3M Learning Objective [1.10.2] Apply Faraday's First & Second Law and Q=It & Q=n(e)F to calculations.

1M Learning Objective [1.3.2] Apply n=V/Vm to calculate volumes of gases at SLC.

$Q = It = 5.60\ A \times 30\ min \times 60\ s/min = 10080\ C$ (1)

$n(e^-) = \frac{Q}{F} = \frac{10080\ C}{96500\ C/mol} = 0.1045\ mol$ (1)

$n(H_2) = \frac{1}{2} n(e^-) = 0.0522\ mol$ (1)

$V(H_2) = n \times Vm = 0.0522\ mol \times 24.8\ L/mol$

$= 1.295\ L = 1.30\ L$ (1)

Question 8 (8 marks)

Scientists help investigate how ethanol can be produced renewably. They decide to use spinach to produce ethanol.

a. Write the equation for the reaction which takes place within the spinach plant to produce glucose. 1 mark

Learning Objective [1.5.3] Write cellular respiration & photosynthesis equations.

D1

$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$ – include UV light on top of the arrow.

b. They then use the glucose to produce ethanol via fermentation with the presence of yeast as a catalyst. D1

i. Write the balanced equation for the reaction which takes place. 1 mark

Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

$C_6H_{12}O_6(aq) \xrightarrow{yeast} 2C_2H_5OH(aq) + 2CO_2(g)$

ii. The ethanol produced is dissolved in water. Propose a method to separate the ethanol and water. 1 mark

D1

Learning Objective [1.5.1] Explain the production of biofuels (biogas, bioethanol & biodiesel).

Simple distillation

c. Is the ethanol produced in this manner renewable? Justify your answer. 1 mark

D1

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

Renewable – it is produced by natural processes (photosynthesis) within a relatively short time

d. Suggest **one** sustainability challenge presented by the use of spinach plants to produce bioethanol in terms of United Nations Sustainable Development Goal 2. Explain your answer by referring to **one** other United Nations Sustainable Development Goal in your response. D3 2 marks

Learning Objective [1.5.2] Identify & explain differences between fossil fuels & biofuels with reference to renewability.

(1 M) Goal 2 – zero hunger – farmland is used to produce bioethanol instead of spinach for consumption as food, which may result in food shortages/insecurity, detracting away from zero hunger.
(1 M) Land is cleared for farmland for production of bioethanol, which can lead to habitat destruction, which is a challenge for goal 15: life on land.

They then repivot their focus and use the spinach for consumption instead. Spinach has the following composition:

Composition	**Mass per 100 g of spinach (g)**
Water	91.40
Cellulose	2.20
Other Carbohydrates	0.42
Protein	2.86
Lipid	0.39
Other Minerals	2.73

Source: U.S. Department of Agriculture. (2019). FoodData Central. Usda.gov. https://fdc.nal.usda.gov/fdc-app.html#/food-details/168462/nutrients

e. Assuming the body does not obtain energy from the other minerals, calculate the energy present in 100 g of the spinach. 2 marks

Learning Objective [1.5.4] Calculate energy obtained from foods.

D2

$0.42\,g \times 16\,kJ/g + 2.86\,g \times 17\,kJ/g + 0.39\,g \times 37\,kJ/g$ (1)

$= 69.77\,kJ$

$= 70\,kJ$ (1)

Question 9 (8 marks)

The same amounts of reactants X and Z are placed in a $7.00\ L$ sealed container and allowed to react according to the equation.

$$X(g) + Z(g) \rightleftharpoons 2Y(g) \quad \Delta H = -345\ kJ\ mol^{-1}$$

The equilibrium constant is known to be 0.650 at SLC.

a. Determine whether the extent of reaction is low, moderate or high. D1 1 mark

Learning Objective [2.7.2] Identify the extent of reaction.

moderate

b. After some time, the amount of X is found to be $3.00\ mol$, and the amount of Y is found to be $5\ mol$.

i. State the amount of Z present at this time. D1 1 mark

Learning Objective [2.7.5] Apply RICE tables to find Kc.

n(X) = n(Z) = 3.00 mol

ii. Determine if the system is at equilibrium. Justify your answer. D2 2 marks

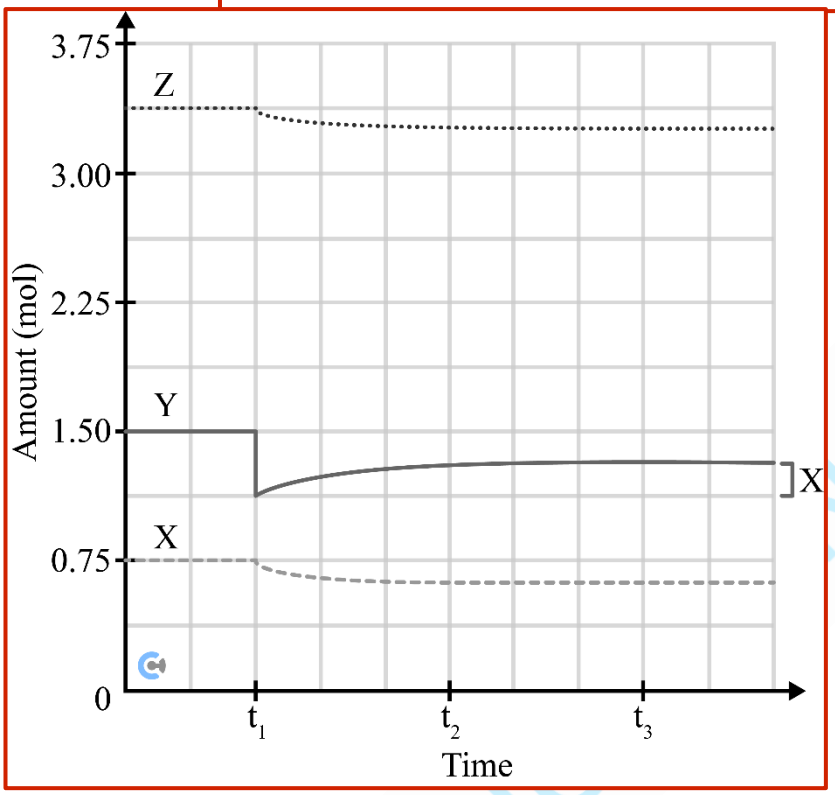
Learning Objective [2.7.4] Apply Qc to find direction of equilibrium shift.

$Q_c = \frac{[Y]^2}{[X][Z]} = \frac{\left(\frac{5}{7}\right)^2}{\frac{3}{7} \times \frac{3}{7}} = 2.78$ (1)

As $Q_c \neq K_c$ ($2.78 \neq 0.650$), system is not at equilibrium. (1)

c. In a different instance, a mixture of the three substances is initially at equilibrium, as shown below in the graph.

Learning Objective [2.8.2] Graph effects of addition/removal of substances or pressure/volume changes on equilibrium system.



i. At t_1, $0.375\ mol$ of Y is removed, whereby equilibrium is re-established at t_2. 1 mark
Complete the graph above to show these changes. D2

ii. At t_2, the volume of the reaction vessel is increased from $7.00\ L$ to $14.00\ L$. D2 1 mark
Complete the graph above to show these changes.

Learning Objective [2.8.2] Graph effects of addition/removal of substances or pressure/volume changes on equilibrium system.

d. To maximise the efficiency of the production of substance Y, both the rate of production and the equilibrium yield should be maximised. What temperature conditions should be used? Justify your answer. D1 2 marks

Learning Objective [2.9.5] Find optimum operating conditions in all circumstances such as the rate-yield conflict.

(1 Mark) - High pressure

(1 Mark) - High pressures will maximise the rate of reaction. High pressures will not affect the position of equilibrium and hence will not affect yield. Thereby, high pressures are used.

Do not write in this area.

Question 10 (10 marks)

The equilibrium system with the following equation is investigated:

$$H_2(g) + I_2 \rightleftharpoons 2HI(g)$$

a. Write the expression for the equilibrium constant. D1 1 mark

Learning Objective [2.7.1] Write equilibrium constant expression & find its value (including units).

$K_c = \frac{[HI]^2}{[H_2][I_2]}$

b. In a 5.0 L container at equilibrium, the amounts of hydrogen and iodine gas are 2.00 mol each and the amount of the hydrogen iodide is 4.00 mol at 200°C. Find the value for the equilibrium constant. D1 1 mark

Learning Objective [2.7.1] Write equilibrium constant expression & find its value (including units).

$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{4^2}{2 \times 2} = \frac{16}{4} = 4.00$

c. The system is kept at the same temperature, but $2.00\ mol$ of hydrogen gas is added.

D2

i. State the direction in which the equilibrium system will shift, justifying your response with reference to a specific principle. 2 marks

Learning Objective [2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system

(1) Shift forwards / Right.

(2) By adding $H_2(g)$, according to Le châtelier's principle the system will partially oppose this change to decrease the $[H_2]$.

ii. Find the final amount of hydrogen gas after the system has re-established equilibrium. 4 marks

D3

Learning Objective [2.7.5] Apply RICE tables to find Kc.

	H_2	+ I_2	⇌ 2HI
ni	2+2	2	4
nc	-x	-x	+2x
ne	4-x	2-x	4+2x
ce	$\frac{4-x}{5}$	$\frac{2-x}{5}$	$\frac{4+2x}{5}$

$K_c = \frac{(4+2x)^2}{(4-x)(2-x)} = 4$

$16+16x+4x^2 = 4(x^2-6x+8)$

$16+16x+4x^2 = 4x^2-24x+32$

$40x = 16$

$x = \frac{16}{40} = 0.4$

$n_e(H_2) = 3.6\,mol$ $n_e(I_2) = 1.6\,mol$ $n_e(HI) = 4.8\,mol$

$\therefore n_e(H_2) = 3.6\,mol$

d. The temperature of the system is then cooled to a lower temperature, whereby the amount of iodine gas is seen to increase. 2 marks

State whether the forward reaction is endothermic or exothermic, justifying your reasoning. D2

(1) As temperature decreases, according to Le châtelier's principle the system will partially oppose the change to increase temperature by favouring the exothermic reaction.

(2) As n($I_{2(g)}$) increased, this shows the backward reaction is favoured.

(3) Therefore the backward reaction is exothermic and forward reaction is endothermic.

1M Learning Objective [2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system.

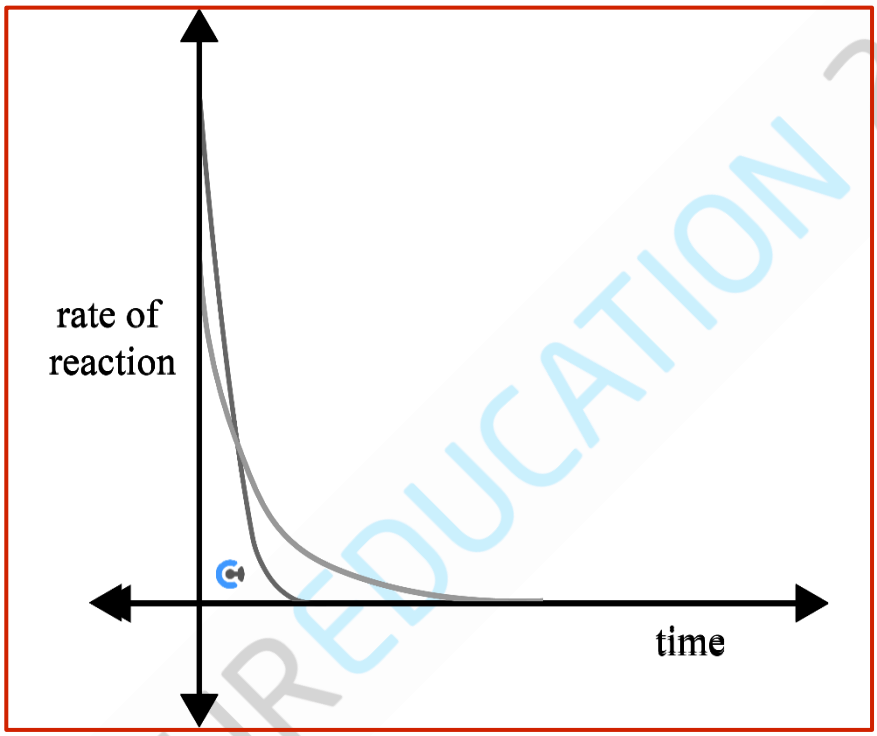
1M Learning Objective [2.9.3] Find the change made to system from equilibrium graph.

Question 11 (5 marks)

A reaction similar to the baking soda and vinegar experiment is undertaken, with $2.0\ g$ solid chunks of sodium bicarbonate, $NaHCO_3$ reacting with $1.0\ M, 20\ mL$ of ethanoic acid, CH_3COOH. The chemical reaction that occurs is as follows:

$$NaHCO_3(s) + CH_3COOH\ (aq) \rightarrow CH_3COONa(aq) + H_2O(l) + CO_2(g)$$

The following graph is recorded.



a. On the same axes above, draw the new graph when powdered sodium bicarbonate is used instead. 1 mark

D2

Learning Objective [2.6.3] Graph differences in rate & yield.

b. Explain the effect on the rate of reaction of adding a suitable catalyst into the reaction beaker. 2 marks

D1

Learning Objective [2.6.2] Explain how temperature & catalyst affect the proportion of successful collisions.

(1 mark) - Adding a catalyst lowers the activation energy by providing an alternative reaction pathway.
(1 mark) - This results in a greater proportion of particles have sufficient energy to overcome this new activation energy barrier, thereby increasing the rate of reaction.

c. Explain the effect on the rate of reaction of adding $3\ mL$ of liquid ethane, C_2H_6 into the reaction beaker. 2 marks

Learning Objective [2.6.1] Explain how factors increase frequency of collisions.

D2

While ethane itself will not interfere with the reaction, more liquid is added, which thereby increases the volume of the reaction vessel. This in turn decreases the concentration of the acid, and thus less frequent collisions will occur which leads to a decrease in the rate of reaction.

4M Learning Objective [1.7.3] Find strongest oxidants/reductants by constructing your own ECS.

3M Learning Objective [1.7.1] Apply the ECS to predict spontaneous reactions.

Question 12 (7 marks)

In electrochemistry, the standard hydrogen electrode (abbreviated SHE), is a redox electrode that forms the basis of the thermodynamic scale of oxidation-reduction potentials.

Its absolute electrode potential is estimated to be $4.44 \pm 0.02\ V$ at $25℃$, but to form a basis for comparison with all other electrochemical reactions, hydrogen's standard electrode potential $(E°)$ is declared to be zero volts at any temperature. Potentials of all other electrodes are compared with that of the standard hydrogen electrode at the same temperature.

Source: IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "standard hydrogen electrode". doi:10.1351/goldbook.S05917

An organic molecule '$X^+(aq)$' is to be placed in the electrochemical series in the following reaction:

$$X^+(aq) + e^- \rightleftharpoons X(s)$$

The organic molecule '$X^+(aq)$' is then placed in a set of **three** reactions as detailed below.

- **Reaction 1:** When placed directly in a beaker and $Zn(s)$ is placed inside, the zinc begins to corrode.
- **Reaction 2:** When placed in a $2.0\ M$ KOH solution, bubbles are produced.
- **Reaction 3:** When placed in a solution with $1.0\ M$ NaBr, no reaction takes place.

Explain the significance of each of the above reactions and observations to provide the range of possible E^0 values of the compound $X^+(aq)$.

In your response, for each of the three reactions, include:

- Any relevant half-equations
- Deduction for the E^0 value.

D3

Reaction 1: X^+ reacts spontaneously, according to the following half-equations:

- Reduction: $X^+(aq) + e^- \rightarrow X(s)$
- Oxidation: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
- Deduction: E^0 value is above $-0.76\ V$
- Marking: (**1 M** for both half-equations) (**1 M** for E^0 value deduction)

Reaction 2: X^+ reacts spontaneously, according to the following half-equations:

- Reduction: $X^+(aq) + e^- \rightarrow X(s)$
- Oxidation: $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$
- Deduction: E^0 value is above $+0.40\ V$
- Marking: (**1 M** for both half-equations) (**1 M** for E^0 value deduction)

Reaction 3: X^+ does not react spontaneously with $Br^-(aq)$:

- Deduction: E^0 value is below $+1.09\ V$
- Marking: (**1 M** for saying non-spontaneous/no reaction with Br^-) (**1 M** for E^0 value deduction)

Conclusion: (**1 M**) Range of E^0 is between $+0.40\ V$ and $+1.09\ V$.